Journal of Archaeological Science 53 (2015) 178–189

Contents lists available at ScienceDirect

Journal of Archaeological Science

journal homepage: http://www.elsevier.com/locate/jas

Artifact preservation and post-depositional site-formation processes in an urban setting: a geoarchaeological study of a 19th century neighborhood in Detroit, Michigan, USA

Jeffrey L. Howard [a, *], Krysta Ryzewski [b], Brian R. Dubay [a], Thomas W. Killion [b]

[a] Department of Geology, Wayne State University, Detroit, MI 48202, USA
[b] Department of Anthropology, Wayne State University, Detroit, MI 48202, USA

ARTICLE INFO

Article history:
Received 8 May 2014
Received in revised form
16 September 2014
Accepted 2 October 2014
Available online 15 October 2014

Keywords:
Pedogenesis
Pedoturbation
Artefact weathering
Microartefact

ABSTRACT

A geoarchaeological study was carried out to assess levels of artifact deterioration occurring in a historic-period urban soil during the 20th century. The study site is a former house-lot in a park created in 1919 by demolition of a residential community in Detroit, Michigan, USA. The results show that despite nearly a century of burial in an urban soil impacted heavily by pollution and other anthropogenic activity, many 19th century artifacts are remarkably well preserved. The observed weathering stability sequence of glass > bone > mortar > plaster > paint is consistent with decreasing solubility product values of the corresponding principal mineral constituent (glass < apatite < portlandite < gypsum < cerrusite). Even severely weathered 19th century nails and mortar can often be distinguished using optical petrographic and SEM-EDAX methods. The excellent state of artifact preservation is attributed to a calcareous soil microenvironment, and artificial compaction which limited the weathering effects of water and oxygen. Artifact preservation was further enhanced by burial beneath a thick biomantle created by the casting activity of an invasive species of earthworm. However, *Lumbricus terrestris* may now pose the greatest threat to artifact preservation because casting and burrowing activities are decreasing bulk density, and promoting the diffusion of air and water into the soil. Early excavation is recommended to recover artifacts in soils impacted by the combined effects of urban pollution and earthworm burrowing. Anthropogenic microparticles smaller than those normally classified as microartifacts were found to be useful indicators of human occupation.

1. Introduction

Previous geoarchaeological studies suggest that environmental changes resulting from anthropogenic activities are having a significant impact on the preservation of archaeological remains buried in soil, particularly in urban settings. Accelerated deterioration rates of buried artifacts, especially metal and other inorganic objects, have been attributed to acid rain, the use of deicing salts on highways, water table lowering, fertilizer applications, and airborne deposition of acid-forming particulates (Kars, 1998; Wilson and Pollard, 2002; Nord et al., 2005; Crow, 2008). A better understanding of artifact weathering mechanisms and site formation processes in urban soils is needed to: 1) ensure the preservation of buried artifacts; 2) improve prospecting techniques for locating sites needing rescue or early excavation, 3) develop better methods for post-excavation preservation, and 4) aid in the identification of highly corroded or weathered objects. Many previous studies of prehistoric sites have shown that, in addition to obtaining information about chronology, building episodes, and settlement patterns, a clear understanding of the geoarchaeological factors of site formation is critical for an accurate interpretation of stratigraphy and artifact context (Schiffer, 1983, 1996; Amour-Chelu and Andrews, 1994; Canti, 2003; Holliday, 2004). However, there have been relatively few studies focused on soil morphogenesis and site formation at historic-period North American sites, especially in urban settings (Davidson et al., 2006; Milek and Roberts, 2013; Prokof'eva et al., 2001).

The purpose of this study was to assess the levels of artifact deterioration which have occurred at a historic-period site since the beginning of the 20th century. We investigated the effects of anthropogenic activities on archaeological site formation and artifact preservation at a former house-lot in Detroit, Michigan, USA.

* Corresponding author.
E-mail address: jhoward@wayne.edu (J.L. Howard).

http://dx.doi.org/10.1016/j.jas.2014.10.004

The study site has been parkland since it was created ~1919 A.D. when buildings from a mid to late 19th century residential community were demolished. The park is underlain by artifact-rich anthropogenic deposits and is located in an urban setting adjacent to a train station, heavily trafficked streets, and industrial land. In this study, we documented post-depositional site formation processes in the field and examined the effects of weathering on artifacts using optical and scanning electron microscopy.

2. Materials and methods

2.1. Study site and geologic setting

The site studied is Roosevelt Park in the Corktown neighborhood about 1.5 km west of Detroit City Hall (Fig. 1A). Corktown is a largely residential area of about 20 ha that grew rapidly after the Great Irish Potato Famine of the 1840s when Irish immigrants from County Cork arrived in large numbers (Delicato and Demery, 2007). It is one of the oldest neighborhoods in Detroit, with some surviving buildings (e.g. "Worker's Row House") dating back to the 1850s (Swaminathan, 2011). Roosevelt Park sits in front of the now derelict Michigan Central Station (MCS), an iconic Detroit landmark. The MCS was built by the Michigan Central Railroad in 1912–1913 as part of a large mass transportation project that included a train tunnel beneath the Detroit River (completed in 1910). Roosevelt Park was designed to be a well manicured esplanade that would serve as a grand entry to the city. In June 1913, the future park site was comprised of 79 parcels of land and more than 100 structures, including houses, barns and shops (Fig. 1B). According to newspaper accounts in the Detroit Free Press, the last three standing buildings were demolished in 1918 by a Mark IV, WWI army tank called *Britannia*. Work on the park began in 1919, and landscaping was completed in 1921. The park's garden was irrigated by the first outdoor sprinkler system ever constructed in the United States. Construction of the MCS predated the first automobile boom of the 1920s, hence the building was designed to be serviced by a well-established electric streetcar system. The MCS began a long decline following the end of the electric streetcar era in Detroit ~1938. Stiff competition with automobile travel resulted in its eventual closure in 1988.

The study site (located at N42°20.705′ and W083°02.925) is near the Detroit River, and adjacent to Windsor, Ontario, Canada (Fig. 1A). Detroit lies on a nearly level plain formed by a series of glacial paleolakes during the Port Huron phase of late Wisconsinan time about 12,400 yr BP. Roosevelt Park lies on the bed of paleolake Elkton of Sherzer (1916) at an elevation of 200 m. Detroit is generally underlain by a relatively thin (<6 m thick) glaciolacustrine deposit comprised of weakly stratified clayey diamicton overlain by a discontinuous capping of sand usually < 1 m thick (Howard, 2010). The study area has a humid-temperate (mesic) climate, a mean annual temperature of 9 °C (49 °F), 99 cm yr^{-1} of precipitation, and a frost line at 107 cm depth. The Pewamo Series (Typic Argiudoll), Metamora Series (Udollic Ochraqualf), and Blount Series (Aeric Ochraqualf) are native soils that are widespread on the somewhat poorly drained lakebed plains beneath Detroit (Larson, 1977).

2.2. Archaeological and geological field methods

Sanborn maps show the site studied is located at what was formerly the corner of Dalzelle and 15th Street (Fig. 1C and D). In 1889 the site, referred to as Lot #1, was occupied by a one story house, a two story barn, and another outbuilding possibly used as a privy (Fig. 2A). Sanborn maps show that additions were made to the top and rear of the house by 1897. The privy had been removed and a new, somewhat larger barn had been constructed. The map from 1915 shows a similar configuration of buildings. Sixty-one archaeological test-pits (30 × 30 × 60 cm in size) were excavated in Lot #1 using a staggered rectangular grid with a 4 × 2 m spacing (Fig. 2A). Each pit was screened for artifacts at 25 cm depth intervals, a general soil profile description was logged, and the types, numbers and weights of artifacts collected from each level recorded.

In addition to these archaeological test-pits, two separate pits (SP-1, SP-2) were dug within the archaeological grid, screened for artifacts at 10 cm depth intervals, and detailed soil profile descriptions collected. For comparison, detailed soil profile descriptions were collected from two additional pits (SP-3, SP-4)

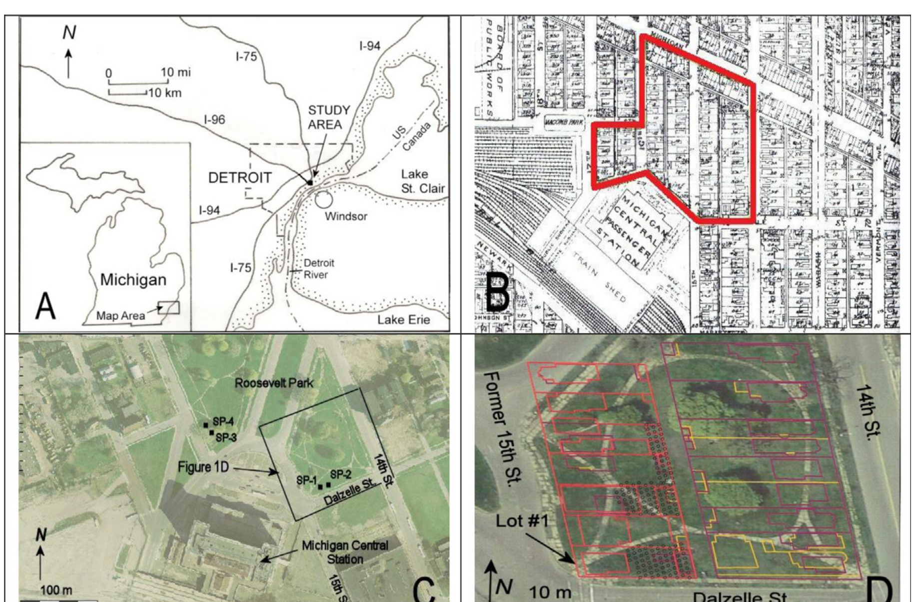

Fig. 1. Maps of the site studied in Detroit, Michigan: A, Location of the study area in southeastern Michigan; B, Housing tracts adjacent to Michigan Central Station ca. 1915 before demolition to create Roosevelt Park; C, Roosevelt Park in 2013 showing site studied; D, Locations of former house lots based on Sanborn maps.

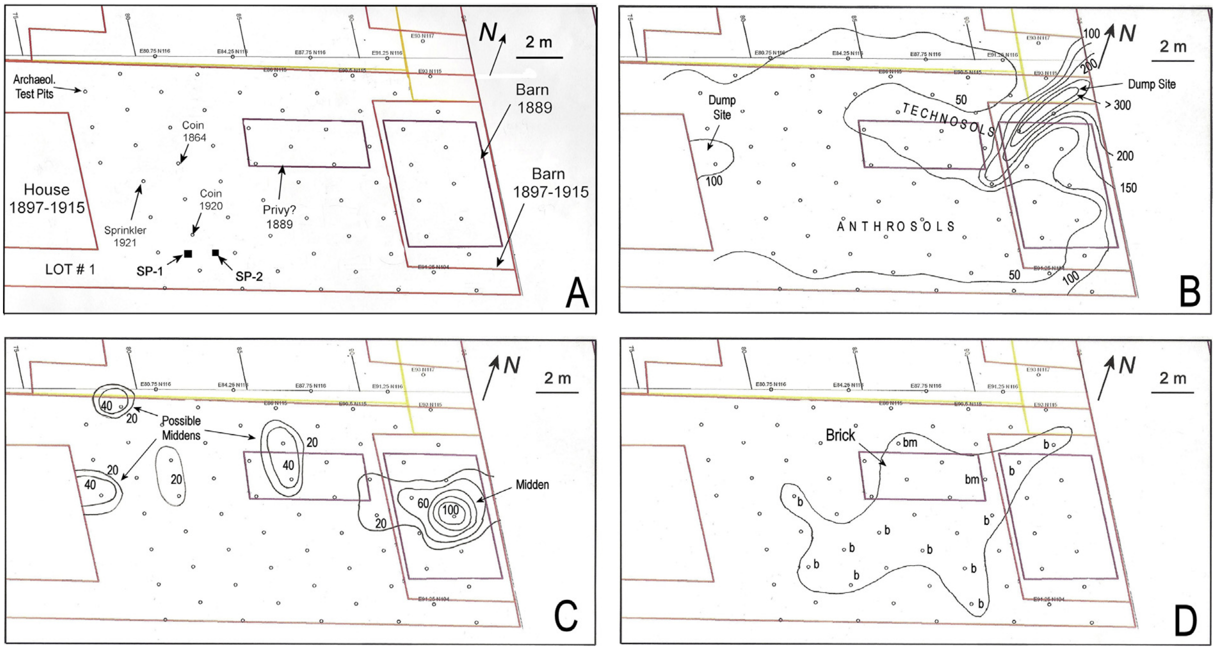

Fig. 2. Archaeological characteristics of house-lot studied in Roosevelt Park: A, Archaeological grid configuration, and locations of soil description test pits, former buildings, and key archaeological finds. Isopleth maps showing spatial distribution of artifacts: B, Contours on total numbers of artifacts present in test pits; C, Contours on total numbers of bones and bone fragments; D, Area where brick (b) and mortar (m) fragments were present.

which were excavated on the west side of the park, beyond the limits of the archaeological grid, and also screened at 10 cm depth intervals. Soils were described (Soil Survey Staff, 2010) and classified (Soil Survey Staff, 2014) using standard USDA-NRCS methods. Soil compaction was assessed by penetrability measurements at ten spots within the archaeological grid using standard methods (Bradford, 1986). Anthropogenic soil horizons are designated by "ˆ" and horizons containing artifacts by "u." Parent materials are classified into two basic types. Human-altered material (HAM) was formed in place either by deep mixing, excavation and replacement from a single pedon, or truncation and removal of the surface soil. Human-transported material (HTM) was formed by excavation of material from one pedon and mixing with materials from other pedons, or by moving earth material horizontally onto a pedon from other sources, usually with the aid of hand tools or mechanized equipment (Soil Survey Staff, 2014). HAM-type and HTM-type soils correspond to Anthrosol and Technosol Reference Soil Groups (World Reference Base), respectively (IUSS Working Group, 2006).

2.3. Lab methods

One kilogram samples of each soil morphological horizon were collected in uncontaminated plastic bags and stored at 4 °C until analysis. Soil samples were dried and sieved to obtain the <2 mm fraction for all analyses. Standard methods were used to determine particle size distribution (pipette method), pH (1:1 soil/solution), total organic C (combustion at 900 °C after removal of carbonates using 1 M NaOAc), cation exchange capacity, exchangeable bases, and % base saturation (Singer and Janitzky, 1986). Carbonate content was determined by measuring Ca using 1.0 g samples of finely ground soil and 20 ml of 1 M NaOAc, shaken for 5 h on a wrist-action shaker (reported as $CaCO_3$). Fe-oxide content was measured using a slightly modified DCB method of Mehra and Jackson (1960). Fe-oxide contents are reported as Fe_2O_3. Soil pH was measured in distilled–deionized water (1:1 soil/solution) using an Oakton 35630-02 unit. An earthworm count was made by collecting all of the soil to a depth of 15 cm from a 1 m^2 area of ˆA-horizon, and dry sieving.

In this study, we examined microparticles in the 90–150 μ fraction. Hence, the term anthropogenic microparticle is used because this is well below the size range (0.25–2.00 mm) used previously to define microartifacts (Dunnel and Stein, 1989). Anthropogenic microparticles were obtained by wet-sieving, following removal of soil organic matter by soaking overnight in 30% H_2O_2, and grains collected by hand-picking under a reflected light microscope. Scanning electron microscopic analysis was carried out with gold coatings using a Hitachi S-2400 scanning electron microscope equipped with an energy dispersive x-ray spectrometer (SEM-EDAX analysis). Confidence limits (error polygons) for elemental analyses were calculated as: $CI = tS/\sqrt{n}$, where CI is the confidence interval ($P = 0.05$), t is the tabulated value of Student's t-distribution, S is the standard deviation, and n is the number of particles analyzed. Weathered macroartifacts were studied petrographically, and by backscattered electron microscopy, using polished thin sections.

3. Results

3.1. Archaeological materials

Artifacts were generally very sparse in the upper part of the ˆAu horizons studied, and only found in abundance below ~20 cm depth. The most common types by far were metal, glass, ceramics and bone (Fig. 3). Metal artifacts were mainly cut nails, but included railroad spikes. Cut nails were used widely in Detroit during the late 19th century, and produced from local sources of bog iron (Sherzer, 1916). Glass artifacts were largely fragments of bottles and window pane, but some intact bottles were unearthed (Swaminathan, 2011). Ceramics were mostly terracotta and stoneware kitchen items, but some porcelain doll parts were found. Bones were primarily derived from cows and sheep, and often showed evidence of butchering. Much less frequent were waste building materials, such as wood, brick and mortar, and personal items such as clay pipes,

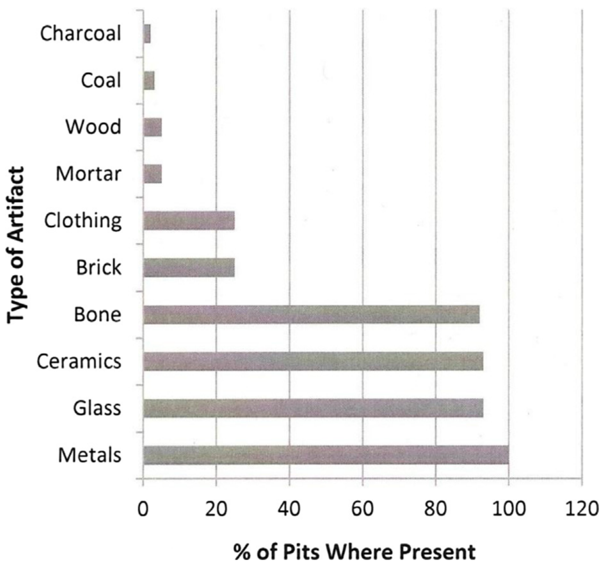

Fig. 3. Abundance of artifacts at the site studied.

buttons, bits of leather and cloth, and jewelry. Other artifacts included occasional fragments of coal and charcoal. An 1864 Indian head penny and a 1920 buffalo nickel were found which, perhaps coincidentally, span the inferred time frame of human occupation. A sprinkler head dated 1921 was also uncovered.

Our maps (not shown) indicate that metal, glass, ceramic and bone artifacts were scattered across the site without any discernible pattern. However, there is a spatial association between the former locations of buildings and the total number of artifacts excavated (Fig. 2B). The greatest concentration was in a narrow swath in the northeastern corner of the lot where more than 1000 artifacts were found. The highest concentrations of animal bones were found in the vicinity of the outbuildings, and at the rear of the house (Fig. 2C). Brick fragments were scattered across a wide swath in the central part of the lot (Fig. 2D).

3.2. Soils

Test-pits indicate that the study site is underlain by about 1.5 m of glaciolacustrine sand resting on clayey diamicton. Hence, the soils are generally developed in sandy parent materials. Three distinct soil types were distinguished based on increasing levels of anthropogenic disturbance (Supplemental Data Table 1). The weakly disturbed anthrosol (SP-1) resembles the native Pewamo soil (Typic Argiudoll), with a relict 7.5YR4/6 (reddish-brown) cambic B horizon (Fig. 4A), but it has an anomalously thick, organic-rich ˆAu horizon (anthropic epipedon) containing artifacts. The moderately disturbed anthrosol (SP-2) is an ˆAu–ˆCu profile developed in HAM (Fig. 4B) formed as a result of anthropogenic mixing A and B horizon materials. The strongly disturbed technosol (SP-3 and SP-4) is developed in a layer of HTM (Fig. 4C) 40–60 cm thick formed by excavation and backfilling, before or during, park construction. The spatial distribution of anthrosols corresponds to the area of relatively low numbers of artifacts, found closer to the surface, in the western and central parts of Lot #1 (Fig. 2B). Technosols are generally found in the vicinity of outbuildings, particularly the barn, where the A and B horizons were stripped off completely in some places. The HTM is typically organic-rich and comprised of soil organic matter and organic wastes incorporated during anthropogenic deposition. Overall, there appears to be a positive correlation between HTM thickness, and the total number of artifacts present. All three soil types have a higher penetrability ($\geq$35–50 psi), compared to sandy native soils (20–30 psi) in the area, attributed to artificial compaction.

The ˆAu horizons of the anthropogenic soils are generally thicker and have a much lower chroma than native soils. The anthropogenic soils are characterized by higher values of exchangeable Ca, K and Na, pH, and carbonate, Fe-oxide and organic matter content (Supplemental Data Table 2). The ˆCu horizons have a higher clay content than native soil as a result of artificial mixing. On the west side of the park, where the HTM contained more abundant brick and mortar (SP-3 and SP-4), there is visible evidence of pedgenic carbonate in the ˆCu horizon, and a calcic (k) horizon was present.

Open burrows and krotovina filled with the casts of *Lumbricus terrestris* were conspicuous in all three soil types (Fig. 4). They were found throughout the ˆAu and ˆCu horizons, and extended into the 2Ab horizon and the underlying sandy 2C1 of SP-3. One burrow containing a very large live worm extended to 1.4 m depth. Approximately 100–133 worms m^{-2} were present, about 75% of which were probably mature animals (>6–10 cm in length). Microscopic analysis showed that the ˆAu horizons were comprised of copious quantities of earthworm casts.

3.3. Analysis of weathered artifacts

Although coins, bone, wood and some nails were in an excellent state of preservation, glass bottles were often characterized by a conspicuous iridescence, and nails and mortar were usually moderately to severely weathered (Table 1). Petrographic analysis showed that mortar clasts which appeared in the field to be

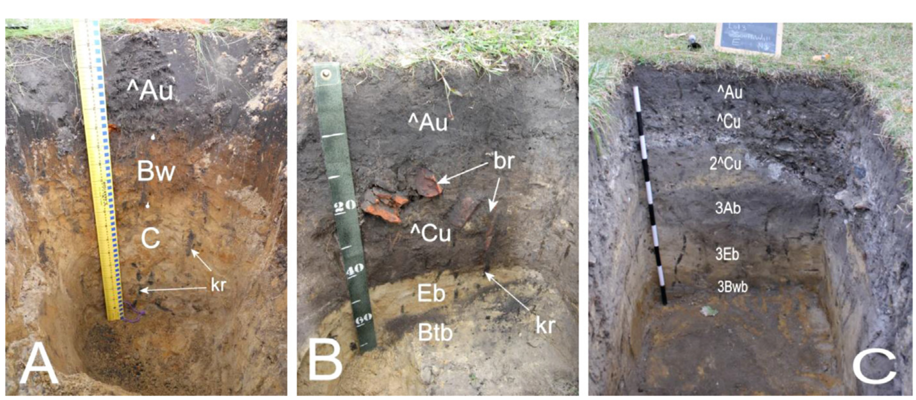

Fig. 4. Soil profiles in Roosevelt Park: A, Weakly disturbed anthrosol formed in human-altered parent material (SP-1); B, Moderately disturbed anthrosol formed in human-altered material resting on sandy glaciolacustrine sediments (SP-2); C, Strongly disturbed technosol formed in human-transported material resting on buried native soil (SP-3). Note lack of artifacts in the upper 23 cm. kr, krotovina; br, brick. Scales in cm or 10 cm intervals.

weathered are riddled with voids (Fig. 5A). The voids were formed by dissolution of cement matrix, and some are exceptionally large and lined with acicular crystals 2–10 μ in size. These data suggest that carbonate is leaching from weathered mortar clasts in the ^Au horizon, and reprecipitating in the subsoil thus forming a ^Cku horizon (Supplemental Data Tables 1 and 2). Fig. 5B shows a zone of laminated and crenulated matrix, probably formed while the cement paste was flowing, adjacent to a large void lined with acicular crystals. Electron microscopy showed that these crystals are embedded in a calcareous matrix thus forming a felted microtexture (Fig. 5C and D) which is a common primary feature seen in cement (Lane, 2004). SEM-EDAX measurements suggest that the laminae are portlandite, whereas the acicular crystals are probably belite. The absence of sulfur suggests that gypsum and ettringite are not present.

Petrographic analysis of corroded cut nails (Fig. 6A and 6B) showed that the encasing crust is comprised of soil particles held together by iron-oxide cement (Fig. 6C). The typical corroded nail consisted of an undecomposed opaque core (Fig. 6D) surrounded by concentric microlaminae comprised of ferrihydrite (orange) and goethite (brown). SEM-EDAX analyses suggest that particles comprising the orange phase have a laminated micromorphology similar to that observed in thin section. The surface is covered in globules and platy particles that occasionally exhibit a hexagonal crystal form. Previous work showed that this phase was composed primarily of Fe and O, but with trace amounts of Ca, Mg, K, Al, and especially silicon (Howard et al., 2013). Hence, the orange phase was identified as ferrihydrite ($Fe(OH)_3$) based on chemical composition and crystal form. The brown phase, composed primarily of Fe and O, was inferred to be goethite ($FeO(OH)$); and a red alteration product of ferrihydrite was assumed to be hematite (Fe_2O_3). The opaque phase comprising the nail core is comprised almost entirely of Fe, hence it is referred to here as ferrite. SEM-EDAX analyses showed that the ferrite had a laminated microfabric comprised of Fe-, C- or Si-rich. Such microlaminae are typical of hand-forged nails (Jouttijarvi, 2009; Ryzewski et al., 2011).

3.4. Anthropogenic microparticles

Petrographic analysis showed that the fine to very fine sand fraction of the ^Au-horizon of SP-3 is comprised primarily quartz with lesser amounts (~5%) of accessory minerals, mainly garnet, hornblende, epidote, magnetite, mica, tourmaline and zircon. This mineral suite is typical of that found in late Pleistocene sediments of the metropolitan Detroit area (Howard et al., 2012). However, anthropogenic microparticles (AMPs) were found to make up ~40% of the sand fraction. Six distinct types were distinguished on the basis of petrographic characteristics (Table 2). Spherical types are the most obvious and abundant type of AMP, ranging from translucent and light colored (Fig. 7A), to opaque and dark brown to black (Fig. 7C). The typical shape is that of a single, solid microsphere, but SEM analysis shows that some particles are hollow or made up of an agglomeration of two or more microspheres. Others are ellipsoidal or have surface blemishes.

SEM-EDAX analysis showed that there are statistically significant differences in the elemental compositions of AMPs (Fig. 8). The light colored microspheres with a vitreous luster are siliceous in composition, whereas the opaque dark colored types are ferruginous. Electron microscopy previously showed that siliceous microspheres tend to have a smooth surface microtexture, whereas that of the ferruginous type is typically ornate, and sometimes coated in subhedral to euhedral (hexagonal?) crystals of Fe-oxide (Howard et al., 2013). Irregularly shaped, light-colored particles with a dull vitreous luster (Fig. 7B) were also found to be siliceous in composition. These particles invariably contain carbonaceous black inclusions. Other irregularly shaped, angular opaque grains with a dull metallic luster and serrated edges (Fig. 7D) are ferruginous, based on EDAX analysis. These microparticles are similar to the ferruginous microspheres, in that they are coated in subhedral Fe-oxide crystals, and chemically indistinguishable from them. A third carbonaceous category was also distinguished (Fig. 8). These include a type with a dull luster and a conspicuous vesicular microtexture (Fig. 7E), and an angular, black, non-vesicular, opaque type with a bright vitreous luster, resembling obsidian in reflected light (Fig. 7F).

4. Discussion

4.1. Post-depositional site formation processes

The most conspicuous post-depositional site forming process, operating for 92 years since park construction, is melanization (darkening of soil by addition of organic matter), resulting in the development of organic-rich ^A horizons which are black (10YR2/1) and 25–30 cm thick. These topsoils have an organic matter content (~8%) even higher than the 125 year-old park soil studied previously (Howard and Olszewska, 2011), which contained ~6% organic matter, and four times higher than that of native soil (Supplemental Data Table 2). This enrichment is attributed in part to the sprinkler system, which was used in the park for about 67 years, and associated horticultural activities. However, the combustion method was used in this study, hence both pedogenic and geogenic organic matter were measured. A geogenic component is suggested by clasts of unspent coal, charcoal and other carbonaceous artifactual material.

Carbonaceous AMPs may also be contributing to the black ^A horizons as the result of cumulization (addition of particulate matter to the soil surface by wind, water or human activities) involving the fallout of airborne soot and flyash. Microspheres are

Table 1
Chemical weathering characteristics of mineral-based artifacts found in Roosevelt Park and associated solubility products (Ksp) of principal components.

Artifact	Weathering characteristics	Principal component	Ksp	Reference
Brick	Very weak weathering	Illite	$10^{-38.9}$–$10^{-77.0}$	Reesman (1974)
		Glass	Insoluble on historic timescale	Kaplan and Mendel (1982)
Ceramics	Very weak weathering	Glass	Insoluble on historic timescale	Cultrone et al. (2001)
Glass	Weak to moderate iridescence	Glass	Insoluble on historic timescale	Kaplan and Mendel (1982)
Coal-cinders	Very weak weathering	Glass	Insoluble on historic timescale	Kaplan and Mendel (1982)
Nails	Weak to severe weathering	Ferrite	10^{-13}–10^{-17}	Gnanaprakash et al. (2007)
		Vivianite	$10^{-35.8}$	Al-Borno and Tomson (1994)
		Ferrihydrite	$10^{-38.0}$	Schwertmann and Cornell (2000)
		Goethite	$10^{-42.0}$	Schwertmann and Cornell (2000)
Bone	Very weak weathering	Apatite	$10^{-10.2}$	Hettiarachchi and Pierzynski (2004)
Mortar	Severe weathering	Portlandite	$10^{-5.2}$	Duchesne and Reardon (1995)
Plaster	Very severe weathering (?)	Gypsum	$10^{-4.7}$	Al-Barrak and Rowell (2006)
Paint	Very severe weathering (?)	Cerrusite	$10^{-4.65}$	Lindsay (1979)

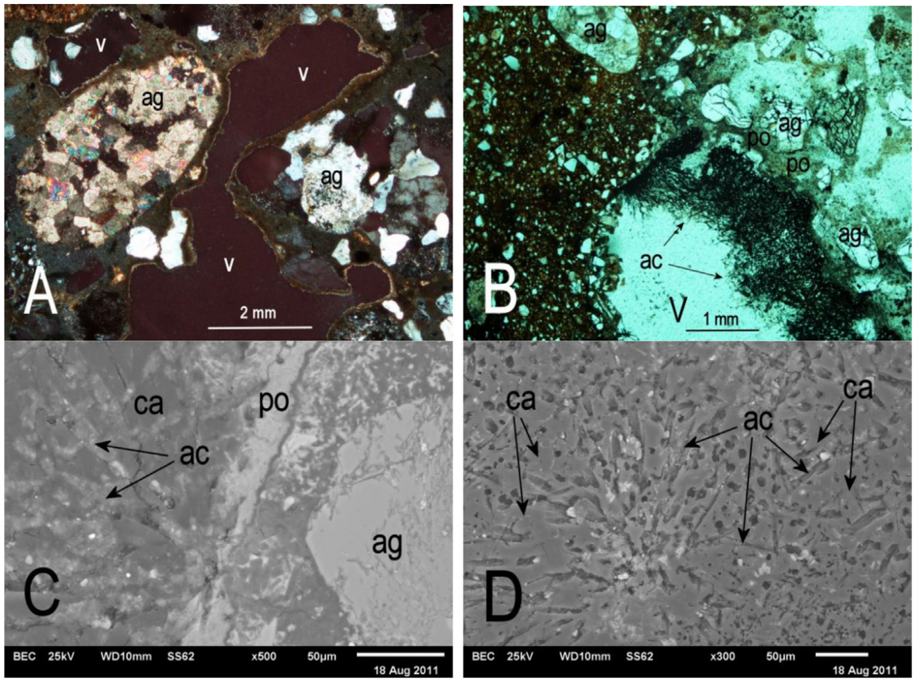

Fig. 5. Weathered mortar clasts from technosol SP-3 in Roosevelt Park: A, Photomicrograph of large void lined with acicular crystals; B, Close up of acicular crystals lining void; C, Back-scattered electron photomicrograph of cement matrix and acicular crystals; D, Close up of acicular crystals. v, void; ac, acicular crystal; ag, aggregate; po, portlandite; ca, calcite.

the principal component of flyash derived from coal-burning (Carlson and Adriano, 1993; Rose, 1996). Hence, the spherical AMPs characterized in this study are interpreted as coal combustion products. The carbonaceous vesicular AMPs, which are visibly cinder-like, and the siliceous non-spherical grains containing carbonaceous inclusions, are also interpreted as coal combustion products (Table 2). Coal-related wastes are often components of urban soils (Bridges, 1991; Schmidt et al., 2000; Koschke et al.,

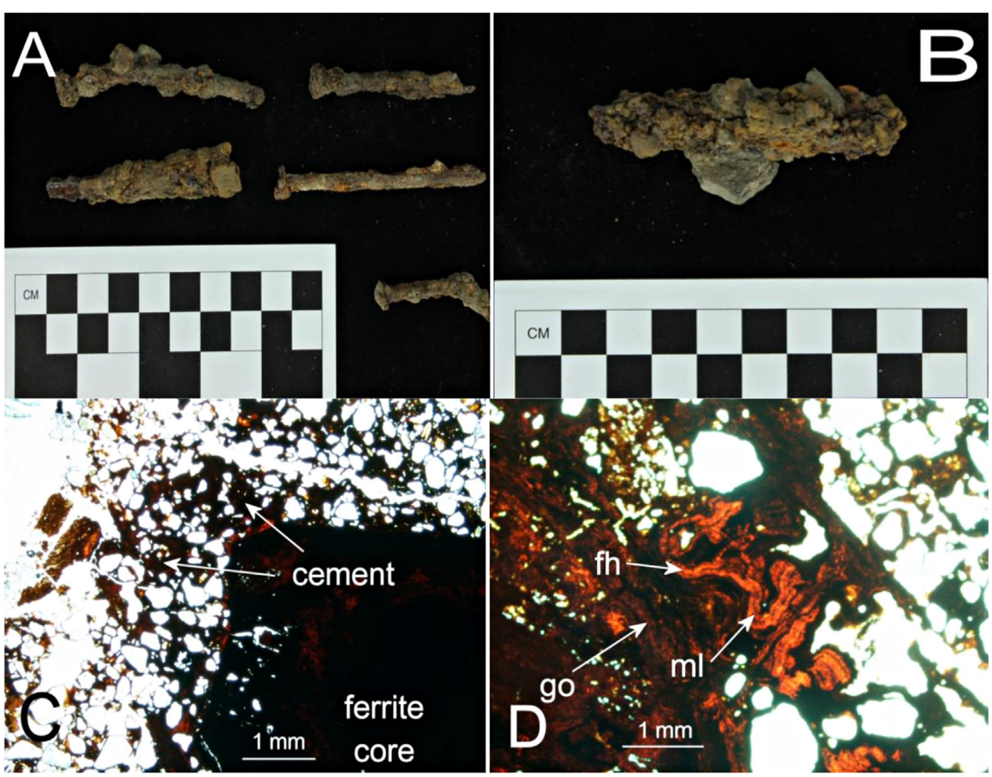

Fig. 6. Weathered wrought-iron nails from anthrosol SP-1 in Roosevelt Park: A, Very weakly oxidized ("cut") nail showing square morphology; B, Heavily corroded square nail encased in an iron oxide cemented soil crust; C, Photomicrograph showing iron oxide cementation of soil particles surrounding ferrite core of nail; D, Photomicrograph of heavily corroded nail showing remnant of ferrite core and zoned microstructure. ml, microlaminae; fh, ferrihydrite; go, goethite.

Table 2
Petrographic characteristics and composition of sand-sized anthropogenic microparticles in Roosevelt Park soil.

Description	Composition					
	Siliceous		Ferruginous		Carbonaceous	
Origin	CCP[a]	CCP	CCP	COM[b]	CCP	COM
Shape	Spherical	Non-spherical subangular to subrounded	Spherical	Non-spherical angular with serrated edges	Vesicular rounded to subrounded	Non-vesicular angular
Color	Light gray greenish-gray	Light to dark greenish-gray	Dark brown black	Dark brown black	Dark gray black	Black
Lustre	Bright to dull vitreous	Dull vitreous	Bright to dull	Dull metallic	Dull glassy	Bright glassy
Opacity	Translucent	Semi-translucent with opaque inclusions	Opaque to semi-translucent	Opaque	Opaque	Opaque

[a] CCP, coal combustion product.
[b] COM, microartifact produced by comminution.

2011). Coal-fired steam locomotives were used heavily at the MCS before WWII, and were still in use as recently as 1958 (Kavanaugh, 2001). Heavy industry also released large amounts of coal combustion products into the atmosphere as shown by photographs, and the sooty patinas still seen on historic buildings in Detroit dating from before ~1920. The non-vesicular carbonaceous and non-spherical ferruginous AMPs were probably produced by comminution of coal and iron artifacts, respectively. This may have occurred during demolition, but previous work shows that fragmentation also may result from trampling and plowing (Stein and Teltser, 1989).

Another conspicuous post-depositional site forming process is pedoturbation resulting from the casting and burrowing activity of earthworms. *L. terrestris* is an invasive species which was brought to Michigan from England by settlers during the 18th or 19th century. The ˆAu horizons studied are interpreted as biomantles. Thus, the sparcity of artifacts near the surface is attributed to burial of artifacts formerly on the ground surface by earthworm casting and upbuilding (Fig. 9). The copper coin dated 1920, found at a depth of ~27 cm, suggests a minimum long-term rate of biomantle accumulation of 3.0 mm yr^{-1}. This is much lower than rates (6–10 mm yr^{-1}) reported elsewhere (e.g., Yeates and Vandermeulen, 1995; Zorn et al., 2008). Roman coins in English soils were buried to a similar depth within 30 years (Darwin, 1881). In any case, these results are similar to those of previous studies showing that pedoturbation by earthworm activity often has a profound effect on the context of artifacts (Stein, 1985; Johnson and Watson-Stegner, 1990; Amour-Chelu and Andrews, 1994).

The ˆC horizons formed in HTM have been affected by calcification (accumulation of pedogenic calcite) as a result of the weathering of mortar clasts in ˆA horizons. The observed dissolution of mortar clasts is probably occurring by reaction of portlandite with carbonic acid (meteoric water) as follows:

$$CO_2 + H_2O \rightarrow H_2CO_3 \tag{1}$$

$$Ca(OH)_2 + H_2CO_3 \rightarrow CaCO_3 + 2H_2O \tag{2}$$

Calcite produced by this reaction is precipitating in the subsurface to form a Ck horizon. The observed weathering of mortar is consistent with the relatively high solubility of portlandite (Table 1). Previous work has also shown that selective dissolution of portlandite occurs during weathering of cement (Marchand et al., 2001) resulting in precipitation of calcite and amorphous silica (Blandine et al., 2008).

Pedocementation has occurred as a result of the weathering of iron artifacts. The soil crust associated with corroded cut nails (Fig. 6C) is cemented by pedogenic iron oxides, and similar to "oxidation halos" observed elsewhere (Gerwin and Baumhauer, 2000). The corrosion rind, with a laminated microstructure (Fig. 6D), is similar to the "dense product layer" of previous work (e.g., Neff et al., 2005) except that ferrihydrite and goethite were the principal components in this study. We have also previously measured trace levels of Cl in the corrosion products (Howard et al., 2013), similar to findings elsewhere (Reguer et al., 2005, 2007). Although deicing salts are a possible source of Cl, which is well known to be highly corrosive to iron artifacts, a likely source is the associated weathered mortar clasts which were previously shown to contain up to several percent Cl (Howard et al., 2013). Iron cementation likely involved fluctuating redox conditions. A similar mechanism has been postulated previously (Neff et al., 2005; Vega et al., 2005; Reguer et al., 2007). During a wetting/thawing event, aerobic bacteria probably depleted O_2 rapidly, and reducing conditions caused partial dissolution of ferrite. Fe^{2+} mobilized by dissolution of ferrite migrated into the surrounding soil along the wetting front until it was sorbed by soil organic matter (Fig. 10). Fe^{2+} was oxidized during a subsequent drying/freezing event, and precipitated as ferrihydrite or goethite depending on the rate of hydrolysis (Schwertmann and Taylor, 1977). The sprinkler system in Roosevelt Park may have been a factor, but corroded nails with oxidation halos are common elsewhere in Detroit indicating that redox fluctuates naturally. The redox gradient must have been steep in order to have strongly corroded nails in the top, and weakly oxidized nails and copper objects in the bottom, of the same ˆAu horizon.

4.2. Site formation

Although post-depositional processes have disturbed the original geospatial patterns of artifacts created by human behaviors, it can be inferred that a dump site is present in the northeastern corner of the lot (Fig. 2B). A hole was dug 1.2 m or more in depth, exposing the underlying clayey diamicton, and backfilled with waste building materials and other artifacts. This was probably done before the 1889 barn was built, based on cross-cutting relationships. Likewise, possible kitchen middens were located behind the house, and likely at the rear of the lot where the barn was subsequently built, based on the large concentration of bones there (Fig. 2C). The function of the other outbuilding is uncertain, but the abundance of bones and other artifacts is consistent with a privy. The spatial configuration of brick fragments (Fig. 2D) and their abundance in the dump suggests that this other outbuilding had a brick-and-mortar root cellar similar to those seen in surviving homes adjacent to Roosevelt Park. Sanborn maps indicate that this outbuilding was razed before1897, perhaps when the new barn was built. The broad spatial distribution of nails, ceramics, glass, bone and personal items in topsoil across the lot suggests that these artifacts were either dropped there before, or spread out during,

park construction, but before development of the earthworm-generated biomantle.

Historic photographs could not be found which show exactly how Roosevelt Park was built, but buildings were probably razed by hand or using fire. Newspaper accounts in the Detroit Free Press detail how building materials were auctioned for construction uses elsewhere. Overall, site stratigraphy suggests that soil used for backfilling was acquired onsite, and just enough was moved to grade and landscape the site during park construction. Human and animal labor was still relied upon heavily during the early 1900s, but photos show that steam-powered tractors were used for road construction near the MCS ca. 1908 (Bak, 1999). There are no local sources of coal, hence it is an artifact imported during the course of human occupation. Coal was used extensively in Detroit for domestic purposes between about 1850 and 1936. Although its inhabitants were still relying heavily on locally produced goods, previous work elsewhere in Corktown (Swaminathan, 2011) shows that commercial products were being imported from as far away as New York (whiskey) and Baltimore, Maryland (oysters).

4.3. Artifact preservation

The site studied has been impacted significantly by anthropogenic pollutants. The beginnings of the Industrial Revolution in Detroit can be traced back to the 1880s, and by 1930 it was the most industrialized city in the United States. The park is downwind from,

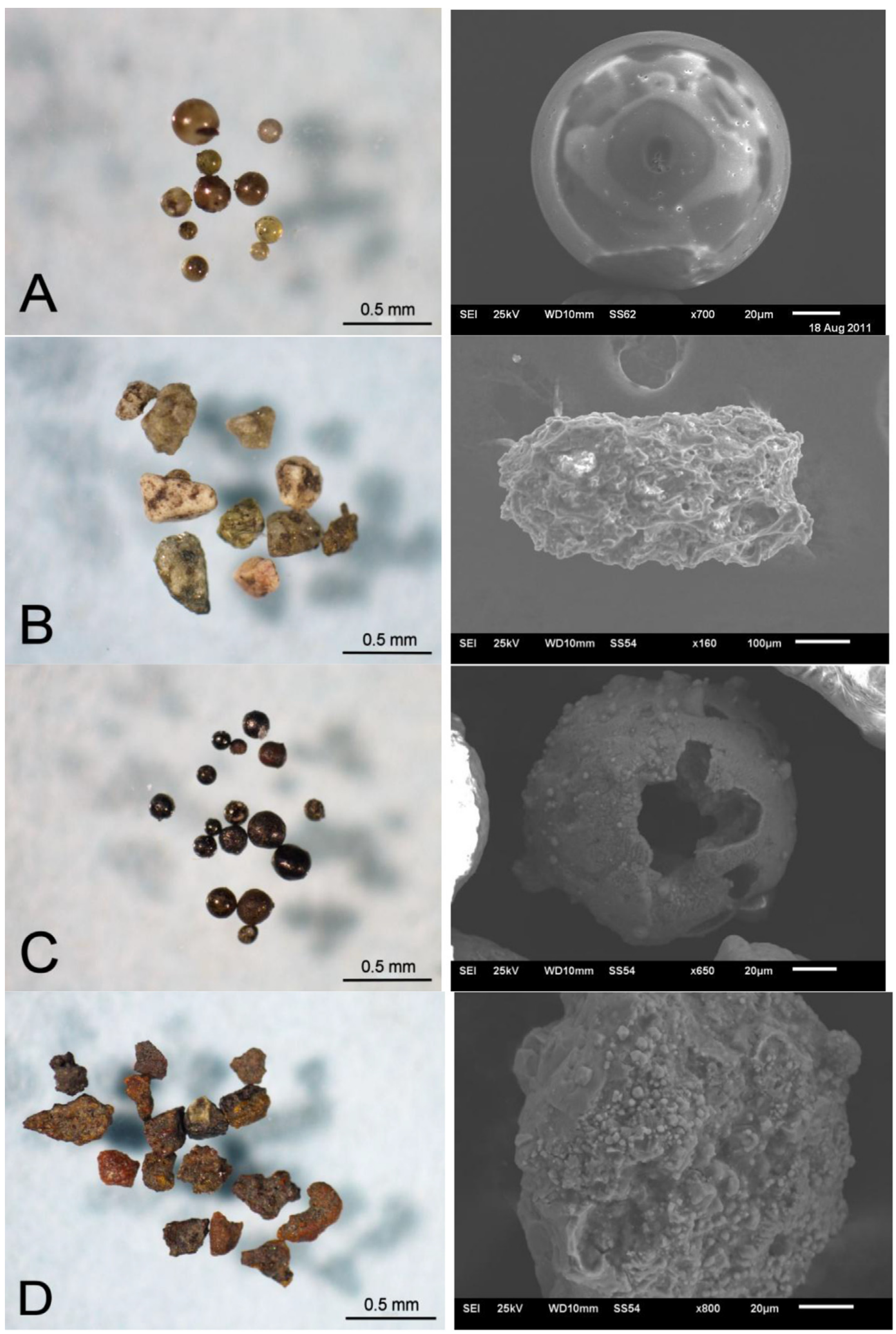

Fig. 7. Petrographic characteristics of anthropogenic microparticles as viewed with petrographic (left) and electron (right) microscopes: A, siliceous spherical, B, siliceous non-spherical; C, ferruginous spherical; D, ferruginous non-spherical; E, carbonaceous vesicular; F, carbonaceous non-vesicular.

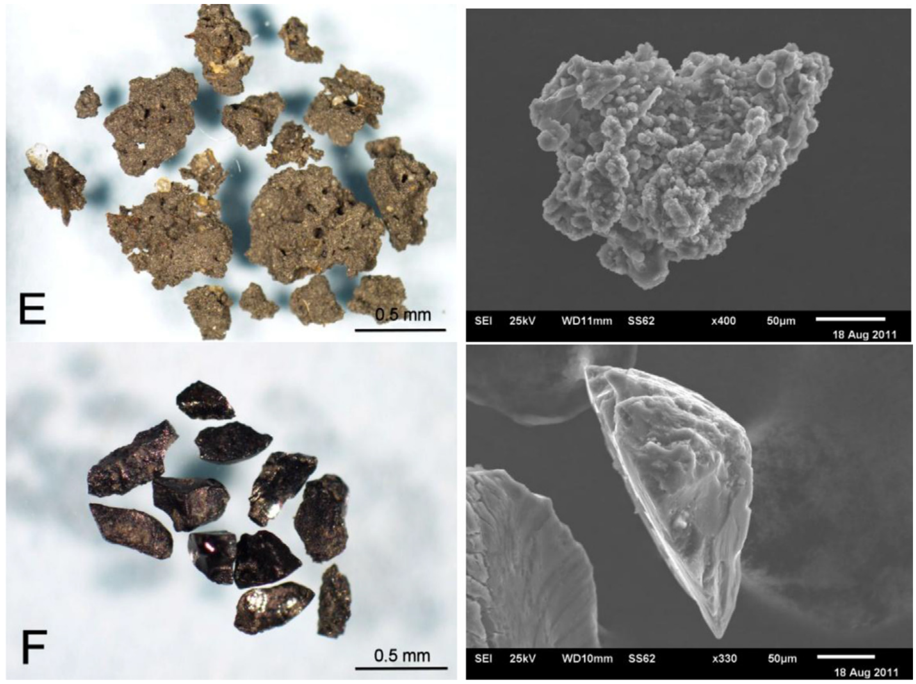

Fig. 7. (*continued*).

and within 5 km of, the most heavily industrialized part of the metro area including the massive Ford Rouge plant in nearby Dearborn. Previous studies suggest that Detroit has been, and probably still is, affected by acid deposition (Dasch et al., 1984), deicing salts (Howard and Sova, 1993), and airborne deposition of particulates (Pancras et al., 2013), in part derived from resuspended urban soil (Zahran et al., 2013).

Despite the intense level of anthropogenic activity, many artifact types were remarkably well preserved. Organic artifacts comprised of bituminous materials or black carbon (coal, asphalt, charcoal, soot) were very well preserved, probably because these carbonaceous materials are relatively recalcitrant to biodegradation. The observed pH range and nutrient status are favorable for microbial activity, hence the low level of biodegradation is attributed to poor O_2 diffusion. Except for some iridescence, bottles and other glass objects were also generally very weakly weathered. Iridescence in ancient glass is known to be caused by leaching of Na ions and the development of surface microlamellae, which may be enhanced by poor drainage (Salviulo et al., 2004; Zorn and Brill, 2007; Michelin et al., 2013). Hence, the observed iridescence is explained by the effects of episodic saturation by the sprinkler system. Brick showed little sign of weathering probably due to a surface coating of glass produced by firing (Cultrone et al., 2004, 2005) which makes it resistant to chemical weathering (Hughes and Bargh, 1982). Coal-cinders are also comprised primarily of glass (Ward and French, 2005), and were very well preserved. Bone was very well preserved, but no paint was found, and only a very small amount of plaster was recovered, suggesting that these materials have weathered away. Mortar was partially weathered, as shown above. Hence, the observed artifact weathering stability sequence is: glass > bone > mortar > plaster > paint. This sequence is explained by a corresponding decrease in the solubility product of the principal mineral constituent (Table 1): glass < apatite < portlandite < gypsum < cerrusite. These results are consistent with previous work (Nord et al., 2005; Crow, 2008) including experimental evidence that gypsum-based drywall can be weathered away in ~30 years (Dubay, 2012).

The excellent state of artifact preservation can be explained in part by a calcareous soil microenvironment. Previous work shows that bone is stable over the range of soil pH values (7.2–8.0) measured in Roosevelt Park, and is especially stable in the presence of pedogenic carbonate (Berna et al., 2004). Iron artifacts can be preserved by a protective coating of carbonate (Neff et al., 2005) or vivianite (Booth et al., 1962), which is highly insoluble (Table 1). Leaching of phosphate from animal bones and formation of vivianite may account for the well preserved nails observed in some places. Even the nail cores in the highly corroded nails were partially preserved once they were encased in a weathering rind of highly insoluble ferrihydrite and goethite. This facilitated the identification of 19th century cut nails despite extensive corrosion.

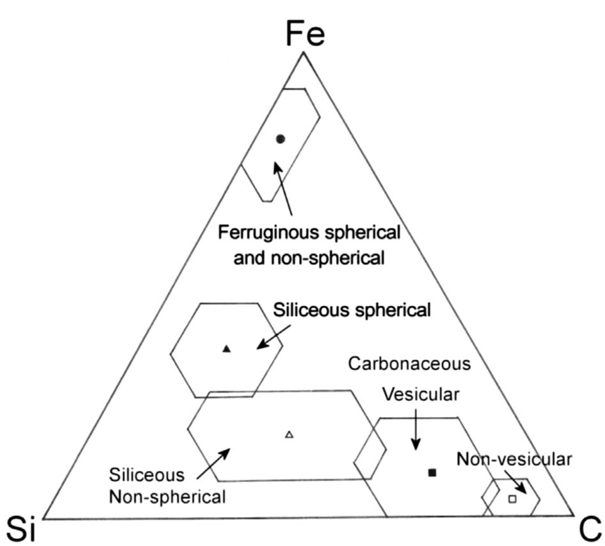

Fig. 8. Anthropogenic microparticle types distinguished by elemental analysis of iron, silicon and carbon. Mean compositions showing error polygons ($p = 0.05$). Modified after Howard et al. (2013).

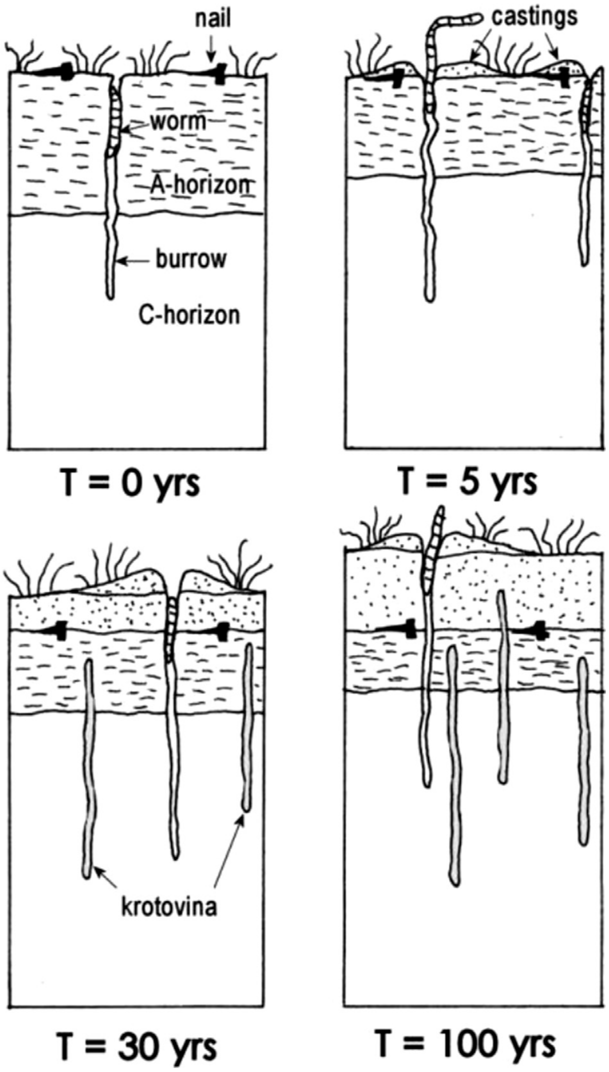

Fig. 9. Interpretation of how casting activity of earthworm *Lumbricus terrestris* causes progressive burial of artifacts over time (*T*).

Mortar from the 19th century was found to be comprised of portlandite, in contrast to Portland cement-based mortar typical of the 20th century, which consists of calcite. This is consistent with historic records indicating that Portland cement was not produced extensively in the U.S. until the 1900s (Van Oss, 2005). Mortar in 19th century Detroit was probably made from "natural cement," i.e. hydraulic cement made from limestone with a high clay content that hardens by hydration. It may have been imported from New York because local sources in Sibley quarry were unsuitable for making hydraulic cement (Sherzer, 1916). In any case, despite significant weathering, it was still possible to distinguish portlandite-based 19th century mortar from calcite-based 20th century mortar using optical petrographic and SEM-EDAX methods.

Artifact preservation was probably enhanced both by burial beneath the earthworm-generated biomantle, and the high bulk density caused by artificial compaction, which apparently restricted the influx of water and air into the soils studied. Unfortunately, there is evidence that earthworm burrowing can reverse the effects of compaction and increase hydraulic conductivity over time (Fraser and Fraser, 1998; Yvan et al., 2012). Hence, the greatest threat to artifact preservation may now be the invasive species *L. terrestris*, which seems to thrive in urban soils of Detroit regardless of the effects of pollution and other environmental limitations.

5. Conclusions

After nearly a century of burial in an urban soil which has been heavily impacted by pollution and other anthropogenic activity, 19th century glass, wood, bone, copper coins, and some iron nails were remarkably well preserved. Paint, plaster, wrought-iron nails and mortar generally show signs of significant weathering. The observed weathering stability sequence of glass > bone > mortar > plaster > paint is consistent with decreasing solubilities of the corresponding principal mineral constituent (glass < apatite < portlandite < gypsum < cerrusite). Despite severe weathering, it is still possible to distinguish 19th century nails and mortar using optical petrographic and SEM-EDAX methods. The excellent state of artifact preservation is attributed to a calcareous soil microenvironment, and artificial compaction which limited the weathering effects of water and oxygen. Artifact preservation was also enhanced by burial beneath a 23 cm-thick biomantle created by the casting activity of an invasive species of earthworm (*L. terrestris*). Ironically, this worm may now pose the greatest threat to artifact preservation because the deep vertical burrows are reversing the preservative effects of compaction, and promoting the diffusion of air and water into the soil. Further study is needed, but the results of this study suggest that early excavation should be carried out to recover artifacts in soils impacted by the combined effects of urban pollution and earthworm burrowing. A variety of anthropogenic microparticles was identified in urban soil using optical petrographic and SEM-EDAX methods. These results

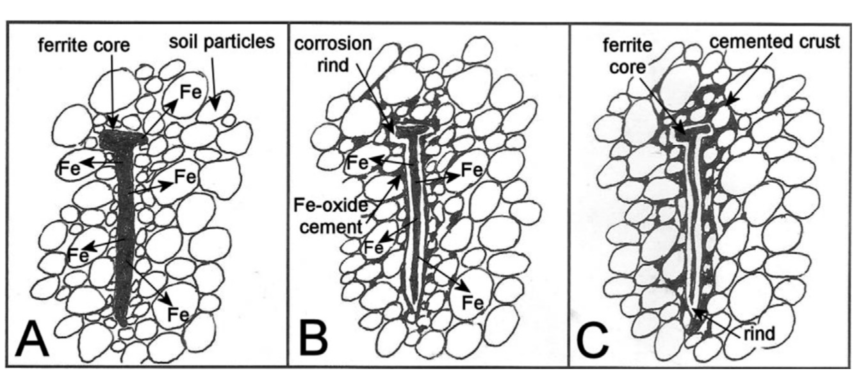

Fig. 10. Interpretive model of progressive pedocementation of soil by iron oxides derived from corroded nails: A, Ferrous Fe leached from ferrite nail core during wetting (reducing) event begins precipitating as ferric Fe in void spaces between soil particles during drying; B, Zone of corrosion forms around remnant of ferrite nail core as leaching and precipitation continues; C, Iron oxide-cemented soil crust has formed around corroded nail.

suggest that microparticles smaller than those normally classified as microartifacts are useful indicators of human occupation.

Acknowledgments

Thanks to the students who assisted with the study as part of the field archaeology classes of 2011 and 2012. Special thanks to two anonymous reviewers, Don Adigian and Graham Sheckels (WSU), Joe Calus and Eric Gano (USDA-NRCS), and the City of Detroit Parks and Recreation Department. Partial funding of the project by a Thesis Research Support Award (Dubay) from Wayne State University and U. S. Geological Survey grant G12AC20181 is gratefully acknowledged. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U. S. Government.

Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jas.2014.10.004.

References

Al-Barrak, K., Rowell, D.L., 2006. The solubility of gypsum in calcareous soils. Geoderma 136, 830–837.
Al-Borno, A., Tomson, M.B., 1994. The temperature dependence of the solubility product constant of vivianite. Geochim. Cosmochim. Acta 58, 5373–5378.
Amour-Chelu, M., Andrews, P., 1994. Some effects of bioturbation by earthworms (Oligochaeta) on archaeological sites. J. Archaeol. Sci. 21, 433–443.
Bak, R., 1999. Images of America: Detroit 1900-1930. Arcadia Press, Chicago, 128 pp.
Berna, F., Matthews, A., Weiner, S., 2004. Solubilities of bone mineral from archaeological sites: the recystallization window. J. Archaeol. Sci. 31, 867–882.
Blandine, A., Bernard, G., Essaid, B., 2008. Use of thermodynamic chemical potential diagrams (μCaO, μCO2) to understand the weathering of cement by a slightly carbonated water. Ceramica 54, 1–6.
Booth, G.H., Tiller, A.K., Wormwell, F., 1962. Ancient iron nails well preserved from apparently corrosive soils. Nature 195, 376–377.
Bradford, J.M., 1986. Penetrability. In: Klute, A. (Ed.), Methods of Soil Analysis, Part 1.Physical and Mineralogical Methods, second ed., Agronomy Monograph 9 American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, pp. 463–478.
Bridges, E.M., 1991. Waste materials in urban soils. In: Bullock, P., Gregory, P.J. (Eds.), Soils in the Urban Environment. Blackwell Sci. Pub., Oxford, England, pp. 28–46.
Canti, M.G., 2003. Earthworm activity and archaeological stratigraphy: a review of products and processes. J. Archaeol. Sci. 30, 135–148.
Carlson, C.L., Adriano, D.C., 1993. Environmental impacts of coal combustion residues. J. Environ. Qual. 22, 227–247.
Crow, P., 2008. Mineral weathering in forest soils and its relevance to the preservation of buried archaeological resource. J. Archaeol. Sci. 35, 2062–2273.
Cultrone, G., Rodriguez Navarro, C., Sebastian, E., Cazalla, O., de la Tone, M.J., 2001. Carbonate and silicate phase reactions during ceramic firing. Eur. J. Mineral. 13, 621–634.
Cultrone, G., Sebastia'n, E., Elert, K., de la Torre, M.J., Cazalla, O., Rodriguez-Navarro, C., 2004. Influence of mineralogy and firing temperature on the porosity of bricks. J. Eur. Ceram. Soc. 24, 547–564.
Cultrone, G., Sebastia'n, E., de la Torre, M.J., 2005. Mineralogical and physical behavior of solid bricks with additives. Constr. Build. Mater. 19, 39–48.
Darwin, C., 1881. The Formation of Vegetable Mould Through the Action of Worms with Observations on Their Habits. John Murray, London, 326 pp.
Dasch, J.M., Cadle, S.H., Wolff, G.T., 1984. Summertime study of acid deposition in the Detroit area. Water Air Soil Pollut. 21, 51–69.
Davidson, D.A., Dercon, G., Stewart, M., Watson, F., 2006. The legacy of past urban waste disposal on local soils. J. Archaeol. Sci. 33, 778–783.
Delicato, A., Demery, J., 2007. Detroit's Corktown. Arcadia Press, Chicago, 127 pp.
Dubay, B.R., 2012. Urban Soil Genesis, Weathering of Waste Building Materials, and Bioavailability of Lead in a Chronosequence at Former Demolition Sites, Detroit, Michigan (M.S. thesis). Dept. of Geology, Wayne State University, Detroit, MI, 107 pp.
Duchesne, J., Reardon, E.J., 1995. Measurement and prediction of portlandite solubility in alkali solutions. Cem. Concr. Res. 25, 1043–1053.
Dunnel, R.C., Stein, J.K., 1989. Theoretical issues in the interpretation of microartifacts. Geoarchaeology 4, 31–42.
Fraser, G.S., Fraser, P.M., 1998. The effects of three earthworm species on soil macroporosity and hydraulic conductivity. Appl. Soil Ecol. 10, 11–19.
Gerwin, W., Baumhauer, R., 2000. Effect of parameters on the corrosion of archaeological metal finds. Geoderma 96, 63–80.
Gnanaprakash, G., Phillip, J., Raj, B., 2007. Effect of divalent metal hydroxide solubility product on the size of ferrite nanoparticles. Mater. Lett. 23, 4545–4548.
Hettiarachchi, G.M., Pierzynski, G.M., 2004. Soil lead bioavailability and in situ remediation of lead- contaminated soils: a review. Environ. Prog. 23, 78–93.
Holliday, V.T., 2004. Soils in Archaeological Research. Oxford Univ. Press, Oxford, England, 465 pp.
Howard, J.L., Sova, J., 1993. Sequential extraction analysis of lead in Michigan roadside soils: mobilization in the vadose zone by deicing salts. J. Soil Contam. 2, 361–378.
Howard, J.L., 2010. Late Pleistocene glaciolacustrine sedimentation and paleogeography of southeastern Michigan, USA. Sediment. Geol. 223, 126–142.
Howard, J.L., Olszewska, D., 2011. Pedogenesis, geochemical forms of heavy metals, and artifact weathering in an urban soil chronosequence, Detroit, Michigan. Environ. Pollut. 159, 754–761.
Howard, J.L., Clawson, C.R., Daniels, W.L., 2012. A comparison of mineralogical techniques and potassium adsorption isotherm analysis for relative dating and correlation of late Quaternary soil chronosequences. Geoderma 179–180, 81–95.
Howard, J.L., Dubay, B.R., Daniels, W.L., 2013. Artifact weathering, anthropogenic microparticles, and lead contamination in urban soils at former demolition sites, Detroit, Michigan. Environ. Pollut. 179, 1–12.
Hughes, R.E., Bargh, B.L., 1982. The Weathering of Brick: Causes, Assessment and Measurement. U.S.G.S and Illinois Geol. Surv. report.
IUSS Working Group, 2006. World Reference Base for Soil Resources 2006: World Soil Resources Report 103. Food and Agriculture Organization United Nations, Rome, Italy, 145 pp.
Johnson, D.L., Watson-Stegner, D., 1990. The soil-evolution model as a framework for evaluating pedoturbation in archaeological site formation. In: Lasca, N.P., Donahue, J. (Eds.), Archaeological Geology of North America, Geol. Soc. Am. Centennial Special vol. 4, Boulder, CO, pp. 541–560.
Jouttijarvi, A., 2009. The shadow in the smithy. Mater. Manuf. Process. 24, 975–980.
Kaplan, M.F., Mendel, J.E., 1982. Ancient glass and the safe disposal of nuclear waste. Archaeology 35, 22–29.
Kars, H., 1998. Preserving our *in situ* archaeological heritage: a challenge to the geochemical engineer. J. Geochem. Explor. 62, 139–147.
Kavanaugh, K.B., 2001. Detroit's Michigan Central Station. Arcadia Press, Chicago, 128 pp.
Koschke, L., Lorz, C., Furst, C., Glaser, B., Makeschin, F., 2011. Black carbon in fly-ash influenced soils of the Dubener Heide region, central Germany. Water Air Soil Pollut. 214, 119–132.
Lane, D.S., 2004. Petrographic Methods of Examining Hardened Concrete: a Petrographic Manual. U.S. Dept. of Transportation Pub. FHWA-HRT-150, 324 pp.
Larson, J.D., 1977. Soil Survey of Wayne County Area, Michigan. U.S. Gov. Printing Office, 83 pp.
Lindsay, W.L., 1979. Chemical Equilibria in Soils. Wiley, New York x pp.
Marchand, J., Bentz, D.P., Samson, E., Maltais, Y., 2001. Influence of calcium hydroxide dissolution on the transport properties of hydrated cement systems. Materials Science of Concrete. American Ceramic Society, pp. 113–129.
Mehra, O.P., Jackson, M.L., 1960. Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate. Clays Clay Miner. 7, 317–327.
Michelin, A., Burger, E., Rebiscoul, D., Neff, D., Bruguier, F., Drouet, E., Dillman, P., Gin, S., 2013. Silicate glass alteration enhanced by iron: origin and long-term implications. Environ. Sci. Tech. 47, 750–756.
Milek, K.B., Roberts, H.M., 2013. Integrated geoarchaeological methods for the determination of site activity areas: a study of Viking Age house in Reykjavik, Iceland. J. Archaeol. Sci. 40, 1845–1865.
Neff, D., Dillman, P., Bellot-Gurlet, L., Beranger, G., 2005. Corrosion of iron archaeological artefacts in soil: characterization of the corrosion system. Corros. Sci. 47, 515–535.
Nord, A.G., Tronner, K., Mattsson, E., Borg, G.C., Ullen, I., 2005. Environmental threats to buried archaeological remains. Ambio 34, 256–262.
Pancras, J.P., Landis, M.S., Norris, G.A., Ram Vedantham, R., Timothy, J., Dvonch, J.T., 2013. Source apportionment of ambient fine particulate matter in Dearborn, Michigan, using hourly resolved PM chemical composition data. Sci. Total Environ. 448, 2–13.
Prokof'eva, T.V., Sedov, S.N., Stroganova, M.N., Kazdym, A.A., 2001. An attempt of integrating the systematic of urban soils into the new Russian soil classification system. Soil Sci. Annu. 64, 24–28.
Reguer, S., Dillman, P., Mirambet, F., Bellot-Gurlet, L., 2005. Local and structural characterization of chlorinated phases formed on ferrous archaeological artefacts by μXRD and μXANES. Nucl. Instr. Methods Phys. Res. B 240, 500–504.
Reguer, S., Dillman, P., Mirambet, F., 2007. Buried iron archaeological artefacts: corrosion mechanisms related to the presence of Cl-containing phases. Corros. Sci. 49, 2726–2744.
Reesman, A.L., 1974. Aqueous dissolution studies of illite under ambient conditions. Clays Clay Miner. 22, 443–454.
Rose, N.L., 1996. Inorganic fly-ash spheres as pollution tracers. Environ. Pollut. 91, 245–252.
Ryzewski, K., Sheldon, B.W., Alcock, S.E., Mankin, M., Vasudevan, S., Sinnott-Armstron, N., 2011. Multiple assessments of local properties, production, and performance in metal objects: an experimental case study from Petra, Jordan. Archaeol. Anthropol. Sci. 3, 173–184.
Salviulo, G., Silvestri, A., Molin, G., Bertoncello, R., 2004. An archaeometric study of the bulk and surface weathering characteristics of Early Medieval (5^{th} – 7^{th} century) glass from Po valley, northern Italy. J. Archaeol. Sci. 31, 295–306.

Schiffer, M.B., 1983. Toward the identification of formation processes. Am. Antiq. 48, 675–706.
Schiffer, M.B., 1996. Formation Processes of the Archaeological Record. Univ. of Utah Press, Salt Lake City, UT.
Schmidt, M.W.I., Knicker, H., Hatcher, P.G., Kogel-Knabner, I., 2000. Airborne contamination of forest soils by carbonaceous particles from industrial coal processing. J. Environ. Qual. 29, 768–777.
Schwertmann, U., Taylor, R.M., 1977. Iron oxides. In: Dixon, J.B., Weed, S.B. (Eds.), Minerals in Soil Environments. Soil Science Soc. Am., Madison, WI, pp. 145–180.
Schwertmann, U., Cornell, R.M., 2000. Iron Oxides in the Laboratory: Preparation and Characterization, second ed. Wiley-VCH, Weinheim. 188 pp.
Sherzer, W.H., 1916. Detroit Folio: Geologic Atlas of the United States. U. S. Geol. Surv. Folio 205, 162 pp.
Singer, M.J., Janitzky, P., 1986. Field and laboratory procedures used in a soil chronosequence study. U. S. Geol. Surv. Bull. 1648, 49 pp.
Soil Survey Staff, 2010. Soil Survey Manual. USDA-NRCS, U.S. Govt. Print. Office, Washington, DC.
Soil Survey Staff, 2014. Keys to Soil Taxonomy, 12^{th} ed. U.S. Department of Agriculture, Natural Resources Conservation Service. 372 pp.
Stein, J.K., 1985. Interpreting sediments in cultural settings. In: Stein, J.K., Farrand, W.R. (Eds.), Archaeological Sediments in Context. Beech Hill Pub., Orono, ME, pp. 5–19.
Stein, J.K., Teltser, P.A., 1989. Size distribution of artifact classes: combining macro- and micro- fractions. Geoarchaeology 4, 1–30.
Swaminathan, N., 2011. The pre-Motor city. Archaeol. Mag. 64, 32–37.
Van Oss, H.G., 2005. Background Facts and Issues Concerning Cement and Cement Data. U. S. Geological Survey Open File Report 2005-1152, 44 pp.
Vega, E., Berger, P., Dillman, P., 2005. A study of transport phenomena in the corrosion products of ferrous archaeological artefacts using ^{18}O tracing and nuclear microprobe analysis. Nucl. Instrum. Methods Phys. Res. B 240, 554–558.
Ward, C.R., French, D., 2005. Relation between coal and fly ash mineralogy, based on quantitative x-ray diffraction methods. In: Proc. World of Coal Ash Conf., Lexington, KY, 14 pp.
Wilson, L., Pollard, A.M., 2002. Here today, gone tomorrow? Integrated experimentation and geochemical modeling in studies of archaeological diagenetic change. Acc. Chem. Res. 35, 644–651.
Yeates, G.W., Vandermeulen, H., 1995. Burial of soil-surface artifacts in the presence of lumbricid earthworms. Biol. Fert. Soils 19, 73–74.
Yvan, C., Stephane, S., Stephane, C., Bouchant, P., Guy, R., Hubert, B., 2012. Role of earthworms in regenerating soil structure after compaction in reduced tillage systems. Soil Biol. Biochem. 55, 93–103.
Zahran, S., Laidlaw, M.A.S., McElmurry, S.P., Filippelli, G.M., Taylor, M., 2013. Linking source and effect: re-suspended soil lead, air lead, and children's blood lead levels in Detroit, Michigan. Environ. Sci. Tech. 47, 2839–2845.
Zorn, M.I., Van Gestel, C.A.M., Eijsackers, H.J.P., 2008. Metal distribution by surface casting of four earthworm species in sandy and loamy clay soils. Sci. Total Environ. 406, 396–400.
Zorn, J.R., Brill, R.H., 2007. Iron Age I glass from Tel Dor, Israel. J. Glass Stud. 49, 256–259.